Development of the San Diego Creek Natural Treatment System

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ABSTRACT

A Natural Treatment System (NTS) Master Plan that includes a watershed-wide network of constructed wetlands was evaluated for treatment effectiveness of dry weather base flows and runoff from smaller more frequent storms in a 120 square mile (311 km^2), urban watershed. The goal of the 'regional retrofit' wetland network is to serve as an integral component in watershed-wide BMPs for compliance with pollutant loading limits (TMDLs) requiring discharge limits of sediments, nutrients, pathogen indicators, pesticides, toxic organics, heavy metals, and selenium. The NTS Plan was assessed with 'planning-level' water quality models that account for the integrated effects of the planned 44 NTS facilities. The NTS Plan is estimated to achieve total nitrogen (TN) TMDL for base flows and reduce in-stream TN concentrations below current standards at most locations. Total phosphorous TMDL targets would be met in all but the wettest years. The fecal coliform TMDL would be met during the dry season, but not all wet season base flow conditions, and not under storm conditions. The NTS Plan is not designed to meet the sediment TMDL, but would capture, on average, about 1,900 tons/yr (1,724,000 kg/yr) of sediment from urban areas. The wetlands are estimated to remove 11% of the total copper and lead, and 18% of the total zinc in storm runoff. The NTS Plan provides a cost-effective alternative to routing dry-weather flows to the sanitary treatment system.

Introduction

San Diego Creek and Newport Bay in Orange County, California have been identified as having impaired surface water quality under California State and U.S. Environmental Protection Agency (USEPA) regulations. The creek and the bay receive runoff from storm events and from agricultural and urban activities in the San Diego Creek Watershed, in addition to natural flows. Federal regulations for impaired water bodies require the establishment of and compliance with discharge limits for the pollutants that are determined to be causing the impairments. These limits are called total maximum daily loads (TMDLs), and are linked to discharge permits established under the National Pollutant Discharge Elimination System (NPDES).

Orange County and NPDES co-permittees, including the local municipalities, are seeking comprehensive solutions for meeting the TMDL requirements. As a component of this effort, the Irvine Ranch Water District (IRWD) has developed a Natural Treatment System (NTS) Plan. The NTS Plan addresses runoff water quality from a watershed-wide perspective, utilizing a network of constructed wetlands. The NTS Plan would build on IRWD's successful use of constructed wetlands by expanding their use throughout a highly urbanized and nearly fully developed watershed. The NTS Plan, therefore, is viewed as an urban retrofit using constructed wetlands as an integral component for compliance with TMDL requirements. The advantage of the NTS system to IRWD, the primary provider of sanitary and potable water services for the watershed, is avoiding the increasingly costly trend in Southern California of routing low flows to sanitary treatment systems.

This paper describes the NTS Plan, the evaluation approach, and the evaluation results of the Plan's effectiveness for contributing to TMDL compliance. An example of the NTS retrofit concept is provided at the end of the paper.

Project Area

Setting. The San Diego Creek Watershed is located in Orange County, California (Figure 1) and covers approximately 120 square miles (311 km^2). The watershed is drained by Peters Canyon Wash and San Diego Creek, and by a number of smaller channels and drainages. San Diego Creek flows into Upper Newport Bay, which contains the 752-acre (3.04 km^2) Upper Newport Bay Ecological Reserve, one of the largest remaining coastal estuaries in Southern California. The San Diego Creek Watershed drains almost 80% of the 154 square miles (398.9 km^2) that are tributary to Upper Newport Bay.

The western and central portions of the watershed are a relatively flat alluvial plain, bordered by the Santiago Hills to the northeast and the San Joaquin Hills to the south. The alluvial plain rises gently from sea level at Upper Newport Bay to about 400 ft (122 m) above mean sea level (msl) at the El Toro Marine Base. The peak elevation in the Santiago and San Joaquin Hills is 1,775 ft (541 m) and 1,160 ft (355 m) above msl, respectively.

The climate is characterized by warm dry summers, and cool intermittently wet winters. The main wet season is from November to April during which widespread general winter storms may last for several days. The average annual rainfall is about 13 inches per year, with 90% occurring in the wet season. Average base flows in San Diego Creek are less than 16 cfs (0.45 cms) during dry weather. The estimated peak 100-year flood discharge is 42,500 cfs (1,203 cms) in San Diego Creek at Newport Bay.

Table 1: Estimated existing and fully developed land uses acreages in the San Diego Creek Watershed.

Land Use	Existing (acres)	Estimated when fully developed (acres)	% Change of watershed from existing to fully developed
Agriculture	11,510	1080	-13.7
Urban[1]	40,210	52,160	+15.6
Open[2]	24,690	23,170	-2.0

[1] Urban is the sum of commercial/light industrial, industrial, mixed use, all residential, roads, and transportation corridors.
[2] Open is the sum of open space-preserve, open space-other, parks, golf courses, and water land use categories.

Land Use. The San Diego Creek Watershed experienced rapid growth and development after World War II. Land-use estimates show that most of the developable lands in the watershed are currently developed (Table 1), with about 15 percent remaining. Much of remaining development would come from continued conversion of agricultural land and from land-use conversion of recently decommissioned military bases.

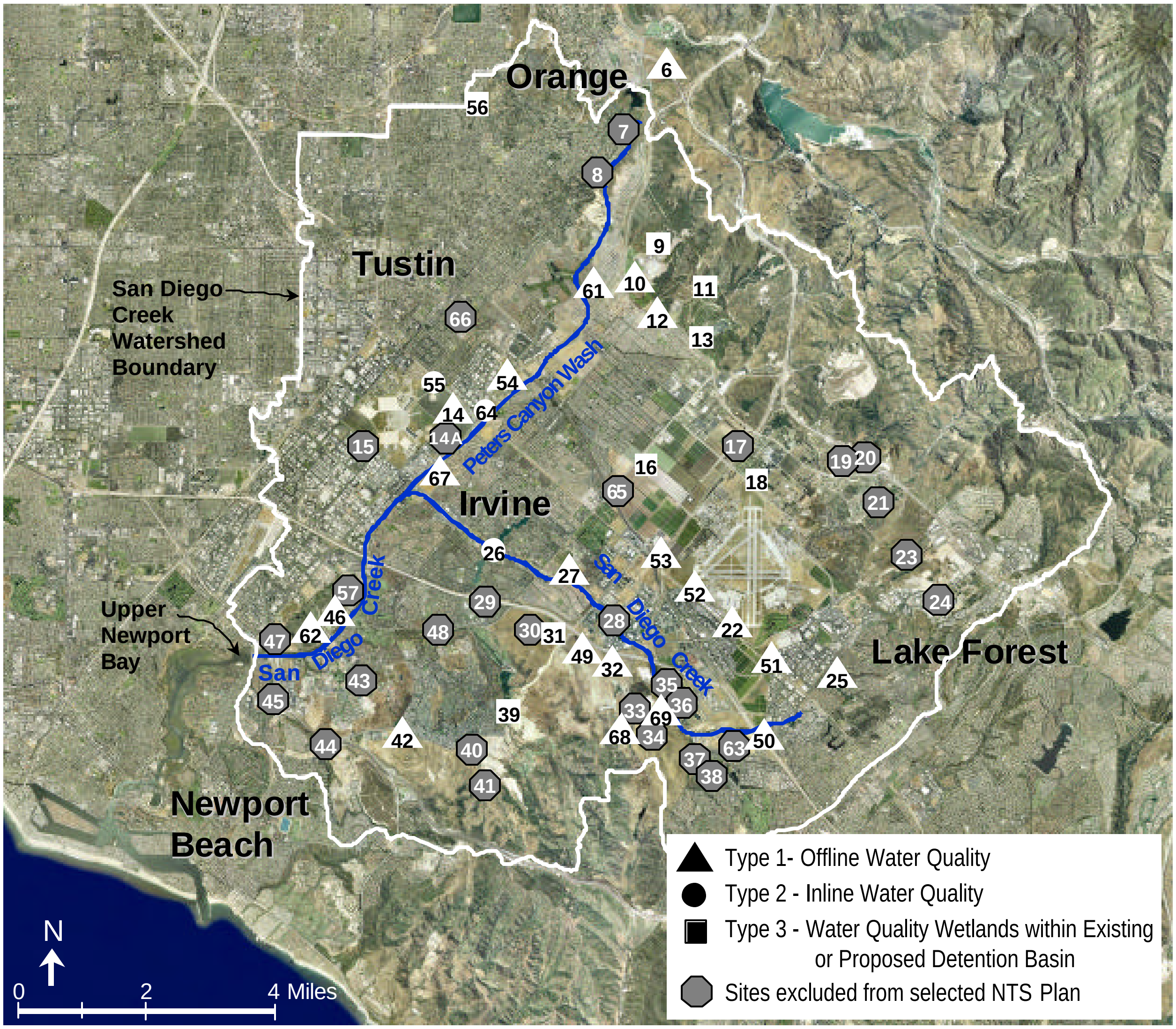


Figure 1: Aerial photograph of the San Diego Creek Watershed showing the locations of NTS Facilities and the types of wetland facilities.

Water Quality Issues and Regulatory Requirements.

Coinciding with rapid growth and development over the past 50 years, water quality in San Diego Creek and Newport Bay has been affected by:

- Excessive sediment loads and sedimentation in Upper Newport Bay, impacting beneficial uses of the bay and wildlife habitat;
- Excessive nutrient concentrations, primarily nitrate from fertilizers, which contribute to the formation of algae blooms in Newport Bay;
- Elevated fecal coliform concentrations in the Newport Bay, especially in storm runoff, which impact shellfish harvesting and recreational uses;
- Elevated concentrations of toxics in portions of Newport Bay, primarily the pesticides Diazinon and Chlorpyrifos, which contribute to acute and chronic toxicity;

- Elevated concentrations of heavy metals in portions of Newport Bay, primarily copper, which "may be causing, or contributing to, toxicity to aquatic life" (RWQCB, 2000); and
- Elevated concentrations of selenium in San Diego Creek from natural origins, with the major source thought to originate from groundwater discharge to San Diego Creek in areas of a historic ephemeral lake in Peters Canyon Wash.

Water quality has been affected by both low-flows resulting from irrigation return flows, car washing, and groundwater recharge to streams, as well as stormwater discharges. Dry weather flows have increased with urbanization of open space and remained about the same, as compared to agricultural activities. The normal generalization that urbanization dries up base flows is typically not true in southern California because irrigation levels significantly exceed natural rainfall. These low flows have caused leaching of pollutants from soils, as well as transport of dissolved nutrients from planted areas.

As a result of these water quality problems, Newport Bay has been designated as an impaired water body by the State of California. In response, TMDLs have been established or drafted for the impairing pollutants (Table 2) (USEPA, 1998a,b; 2002). To address TMDL requirements, Orange County and local municipalities have implemented an array of Best Management Practices (BMPs) for load reduction, regional monitoring activities for the assessment of BMP effectiveness, and public education and coordination efforts. These activities are generally directed towards source control and do not fully address regional treatment needs for compliance with the TMDL requirements.

Table 2: A listing of the constituents included in the San Diego Creek TMDLs, general information about each, and the TMDL loading limits for watershed land uses.

Constituent	General Information	TMDL
Sediment	Load is strongly correlated with rainfall. Annual average load estimate: 250,000 tons; 1998 load was 620,000 tons.	62,500 tons/year to Newport Bay, 62,500 tons/year to the rest of the watershed, based on a 10-year running average.
Nutrients (TN and TP)	Declining trends in 1990's 1986 TN load = 1,448,000 lbs 1998 TN load = 632,000 lbs	Annual total load targets: 298,225 lbs Total Nitrogen/year by 2012 62,080 lbs Total Phosphorus/year by 2007
Pathogens	Fecal coliform bacteria used as an indicator. Goal is to achieve contact recreation standards by 2014.	5 samples/30-days with a geometric mean concentration of 200 organisms /100mL, and no more than 10% of the samples to exceed 400 organisms/100mL
Selenium (draft)	Natural sources from groundwater discharge and surface runoff 1998/99 estimate: 3,248 lbs/year	Annual total load targets = 891.4 lbs. Loads are partitioned into four flow tiers.
Heavy metals	Loads highly variable with rainfall: Total load (lbs) 1998 1999 Copper 15,087 1,643 Lead 10,385 449 Zinc 63,021 3,784	Concentration based TMDLs expressed at four flow tiers. Concentrations are based on the California Toxics Rule objectives using average hardness values of the associated flow tier
Chlorpyrifos & diazinon	Widely used pesticides that are currently being phased out for non-commercial use. Both exceed the chronic concentration criteria in base flow and storm flow conditions.	SD Creek acute and chronic concentration targets, respectively, by 2005: Diazinon - 80 & 50 ng/L Chlorpyrifos – 20 & 14 ng/L
Organochlorine compounds	Legacy compounds that tend to bioaccumulate and have considerable persistence in soils, sediments, and biota. Sources are unknown.	Annual load limits to Newport Bay (g/yr): Chlordane = 346.2; Dieldrin = 287.7; DDT = 475.9; PCBs = 310.3; Toxaphene = 9.8

Natural Treatment System Plan

Plan Development

Various treatment-type control options were evaluated in developing the NTS strategy, including: (1) on-site controls for new development; (2) complete or partial diversion of dry weather base flows and portions of wet weather discharges to the sanitary sewer system; and (3) a regional treatment approach.

Given the urbanized nature of the watershed, a strategy that focuses on on-site controls for new development (or re-development) could not, by itself, meet regulatory requirements in a timely manner, since that strategy would not address pollutants associated with existing urbanization in the San Diego Creek Watershed, nor disperse sources such as groundwater discharges. Diversion of streamflow to the sanitary sewer was determined to be mostly infeasible, given the stringent total dissolved solids requirements for water recycling (an important IRWD water conservation tool), the cost for providing storage and treatment for the large volumes of water, and the need to maintain in-stream flows for riparian habitat and wildlife.

The NTS approach, based on a regional network of constructed wetlands, was determined to be the best strategy for addressing regional water quality treatment needs because: (1) constructed wetlands are an effective and cost-competitive approach for water quality treatment, based on the experience and success of the existing IRWD constructed wetlands in the San Joaquin Marsh (a low-flow treatment marsh already operated by IRWD near Upper Newport Bay), as well as other wetlands both regionally and nationally; (2) constructed wetlands address pollutant sources from existing and future development, as well as disperse sources; and (3) constructed wetlands can enhance habitat and natural resources in the watershed.

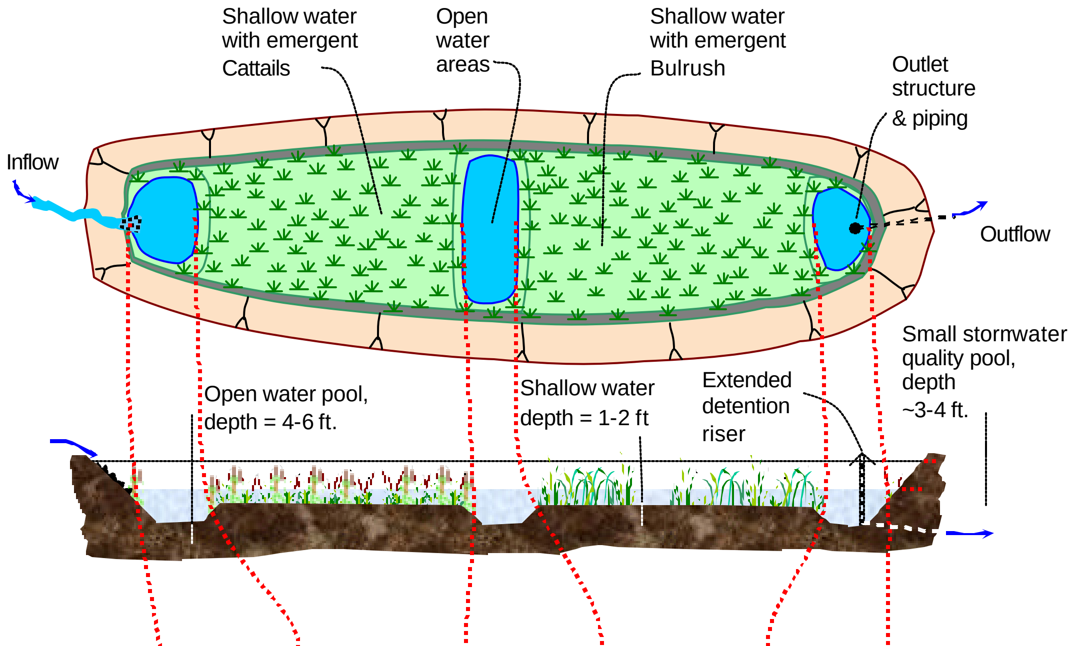
Constructed Wetlands

The facilities envisioned in the NTS Plan are constructed wetlands to improve the water quality of dry weather base flows and the runoff from smaller storms. Constructed wetlands are engineered systems designed to improve water quality by taking advantage of processes occurring in natural wetlands, but in a more planned and controlled system. Constructed wetlands have evolved and gained acceptance during the past 25 years as a practical and cost-effective means for advanced treatment of municipal wastewater and for treatment of urban runoff (Kadlec and Knight, 1996; Strecker, 1996).

A local example is the IRWD constructed wetlands at the San Joaquin Marsh near the mouth of the San Diego Creek Watershed. The IRWD constructed wetlands consists of five treatment cells with 45 acres of open water and 11 acres of marshland vegetation. Water is pumped from San Diego Creek into the wetlands at an average rate of about 7 cfs and has a retention time of about two weeks. Monitoring data indicate that about 200 lbs (91 kg) of nitrate are removed per day during dry weather, reducing the total load to Upper Newport Bay by about 30%. The strategy of the NTS Plan is to expand the success of the IRWD wetlands throughout the San Diego Creek Watershed.

Facility Designs

Each of the over 40 NTS facilities will be tailored to local conditions and constraints; however, most of the NTS facilities share common design features (see Figure 2). Throughout most of the year the water quality wetlands will primarily treat low flows because rainfall events are infrequent in Orange County (10-15 events per year over 0.1 inch (0.25 cm)). During non-storm conditions, water levels in the typical wetlands will be in two general regimes:



	Extended Detention
Main pollutant removed	Sediment
Secondary pollutant removed	Oil and grease, phosphorus, metals, organics
Primary Removal Mechanisms	Sedimentation
Wildlife	None

	Inlet Pool	Cattail Stand	Open Water Pool	Bulrush Stand	Outlet Pool
Main pollutant removed	Sediment, pathogens	Nitrate, phosphorus, metals, pathogens	Pathogens Organic transformation	Organics, pesticides	Pathogens
Secondary pollutant removed	Metals, phosphorus, organics	Organics	Sediment	Nitrate, phosphorus, metals	Organics
Primary Removal Mechanisms	Sedimentation, UV radiation	Nitrification, plant uptake, filtration, sedimentation	UV radiation, volatilizatrion	Nitrification, plant uptake, sedimentation	UV radiation
Wildlife	Mosquito fish, birds	Birds, insect larvae e.g. dragonflies, mosquito fish	Ducks, mosquito fish	Birds, insect larvae e.g. dragonflies, mosquito fish	Ducks, mosquito fish

Figure 2: Generic Design and Removal Mechanisms of NTS Facilities, showing a plan view and providing information on intended pollutant removals in each sub-area of the wetland.

Open water regions typically 4-6 ft (1.2-1.8 m) deep are intended to help distribute the flow uniformly through the wetland vegetation and to trap course sediments. These areas are most effective at removing sediments and pollutants associated with sediments such as phosphorus, metals, and some organic compounds. Open water areas also facilitate destruction of pathogens by exposing them to sunlight.

Shallow water regions 1-2 ft (0.3-0.6 m) in depth are intended to support the growth of emergent wetland vegetation, primarily cattails and bulrushes. These areas are most effective at removing nutrients, and to a lesser extent metals, pathogens, and toxic compounds.

The time required to obtain effective pollutant removal during low flows is estimated to be typically 7-14 days, depending on site conditions and temperature (Kadlec and Knight, 1996). Most NTS sites are designed for a 10-day retention time during low flow conditions.

Sediments and pollutants that tend to attach to sediments are primarily transported by higher flows from storm events. Many of the NTS facilities are designed to detain and treat stormwater runoff by means of reduced flow outlets that drain the stormwater over a period of about 36 hours. The depth of the stormwater quality pool is typically 3-4 ft (0.9-1.2 m) above the normal low flow water level (Figure 2), thus inundating the wetland vegetation. Wetland vegetation would not be destroyed by inundation for short detention periods.

Removal of pollutants from storm runoff will primarily occur by settling processes. Therefore the primary pollutants removed from storm runoff are sediments and pollutants associated with sediments such as phosphorus, metals, and some organic compounds. There will be little or no removal of dissolved nutrients (e.g., nitrate) during detention of storm runoff.

Habitat enhancement is an important aspect of the NTS Plan. The selection and planting of riparian vegetation between the wetlands and the surrounding habitat affects the habitat characteristics of the wetlands. Where feasible, native riparian vegetation will be selected to enhance habitat for endangered avian species.

San Diego Creek has consistently high levels of selenium, which originate from natural sources. A major source of selenium is groundwater discharge to the San Diego Creek in a historical ephemeral lake and marsh region. Selenium was historically immobilized and trapped in the marsh due to the presence of reduced anoxic conditions. Drainage of the swamp in the early 1900's for agriculture allowed oxygenated groundwater to flow through the marsh, creating soluble and mobile forms of selenium that are now being flushed to the creek

Elevated selenium levels must be reduced in accordance with the draft TMDL for selenium. To address the TMDL, the NTS Plan includes one facility for selenium removal (Site 67) located in the historical ephemeral marsh region. The selenium treatment concept is to mimic the selenium sequestrating processes that occurred in the historical marsh in a subsurface flow treatment wetland. Stream water would be diverted through organic rich native soils under anoxic conditions, creating reduced forms of selenium that are immobilized by sorption to the soil particles.

Facility Selection

Potential NTS sites were selected using a simple screening process. Staff at IRWD developed an initial list of potential sites based on their knowledge of the watershed and information contained in their databases. Following field visits, the initially selected sites were assessed by preliminary technical analyses and institutional and community acceptance assessments. This process was followed by successive rounds in which some sites were removed from further consideration, due to technical constraints or other considerations, and replaced with new sites. In total, more than 60 sites were considered for the NTS Plan, of which 44 were retained for detailed assessment. The location of all NTS sites is shown in the aerial photograph in Figure 1.

The NTS facilities are categorized by their location in reference to stream channels and whether they are being added to a flood retarding basin: Type I off-line facilities are adjacent to existing channels and require diversion structures for influent and effluent to the facility; Type II in-line facilities are wetlands that are established within existing stream channels; and Type III facilities are established within existing or planned retarding basins, and make use of the local storm drains.

Evaluation of the NTS Plan

The NTS Plan was evaluated using planning-level water quality models that primarily rely on local hydrologic and water quality data, and data collected on the performance of local and national wetlands. The purpose of the water quality models was to provide planning-level assessments of the NTS Plan alternatives, and to evaluate the NTS contribution to TMDL compliance. The modeling strategy used to evaluate the NTS Plan is summarized in the following steps:

1. Forecast future land uses: The NTS Plan was evaluated under the assumptions of complete development in the watershed ("build-out" conditions) and full implementation of the NTS facilities. The intent was to obtain a measure of the total effectiveness of the NTS Plan under ultimate watershed conditions. Build-out land use conditions were estimated from zoning maps and local agency land-use plans.

2. Forecast hydrology and pollutant loads under build-out conditions: Estimates of flow conditions and pollutant loads were forecasted for future land use conditions using available monitoring information and statistical correlations between current and projected land uses. In cases where there was insufficient monitoring data, land-use based pollutant load estimates were developed from regional monitoring information.

3. Estimate load reductions in the NTS facilities: Water quality models were developed to estimate pollutant loads and load reductions occurring in individual NTS facilities and as a network of NTS facilities. The water quality models take into account the interrelationships of individual facilities that occur when pollutant removals in up-stream facilities affect pollutant loads at down-stream facilities. Separate models were developed for low flow and storm flow conditions and different pollutants were modeled for different flow regimes, depending on the pollutant characteristics and TMDL requirements.

    Low Flow Conditions: Load reduction estimates for low flow conditions were modeled as a first order kinetics process using coefficients derived from data collected at local constructed wetlands. Seasonal rate coefficients were used to account for temperature differences. Flow and load estimates included evaporation losses, and pollutant contributions from groundwater discharge to stream channels. Pertinent assumptions are summarized in Table 3..

    Storm Conditions: The treatment effectiveness of runoff from storm events was assessed on an average annual basis. A 21-year period of recorded rainfall was used to estimate: the annual runoff quantities. Pollutant concentrations were estimated with the event mean concentration (EMC) values from available local and regional monitoring information. Load reduction was estimated with data from the USEPA's Nationwide BMP database (ASCE, 2001; Strecker et. al., 2001). Pertinent assumptions are summarized in Table 4.

Table 3: Approach and Assumptions used in the Low Flow Model.

Parameter / Process	Assumption / Approach
Load reduction	Evaluated with a first-order kinetics model with background concentration.
Steady state	Seasonal average steady state conditions were assumed.
Atmospheric sources	Water and pollutants from atmospheric sources were assumed negligible compared with influents flows and loads.
Stream flow	Estimated with seasonal based empirical relationships that account for projected land-use and groundwater contributions. Equations were developed by regression analysis using available stream flow data and geographical information.
Evapotranspiration	Estimated with available monthly average reference evapotranspiration.
Infiltration	Assumed negligible based on planned use of liners in areas with poor soil conditions.
Background concentration	1 mg/L for total nitrogen; 50 MPN/100 mL for fecal coliform bacteria
First-order rate constant	TN removal: 0.55 and 0.25/day for the dry and wet seasons, respectively. Fecal coliform: 75 m/year (area based)
Residence time	7-14 days
Open water ratio	Open water areas constitute 20% of the wetlands, except near airports where no open water areas were included.
Period of operation	165 days in the dry season; 150 days in the wet season
Influent concentration	Average seasonal concentrations estimated from available monitoring information

Table 4: Approach and Assumptions used in the Storm Flow Model.

Parameter / Process	Assumption / Approach
Annual model	Uses annual rainfall depths to estimate annual runoff volume and pollutant loads.
Sediment sources	Post-construction sediment sources from urban and open space areas. Does not address in-stream sediment sources.
Annual rainfall depth	Determined from monthly rainfall records. Rainfall was reduced by a correction factor to account for events that produce no appreciable runoff.
Runoff volume	Estimated as a function of land-use with the rationale formula where the runoff coefficient is expressed as a linear function of percent imperviousness.
Stormwater pollutant concentrations	Estimated with land-use based Event Mean Concentration (EMC) values from available local and regional stormwater monitoring data.
Capture efficiency	Estimated by routing stormwater runoff volumes obtained from hourly rainfall data through the NTS facilities. Different routing rules were used depending on the facility type.
Background concentration	1 mg/L for total nitrogen; 50 MPN/100 mL for fecal coliform bacteria
BMP performance	Data available from the USEPA's Nationwide BMP data was assumed to be representative of the treatment performance in the NTS facilities.

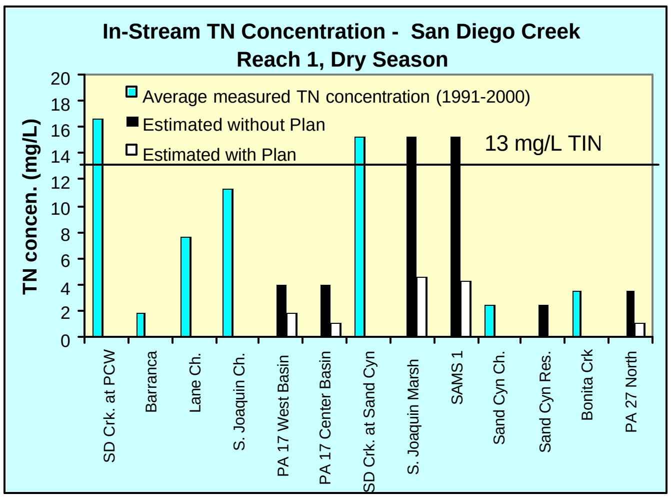
Estimated Nitrogen Removal

Nitrogen removal was modeled only for low flow conditions, consistent with the TMDL requirements. The modeling results indicate that the NTS facilities would remove about 227,500 lbs (103,200 kg) of total nitrogen (TN) annually, and that both dry and wet season TMDLs would be met (Table 5). In general, wet-season TMDLs are more difficult to achieve because loads are higher in the wet season and removal rates are smaller due to lower temperatures and resulting biochemical activity.

The modeling results reveal that a large proportion of the TN removal occurs at the larger sites located in the downstream reaches of the watershed. Smaller sites distributed in the upstream reaches remove less TN on a percentage basis, but contribute to the improvement of 'local' in-stream water quality. Model predictions indicate the NTS Plan would significantly reduce in-stream TN concentrations (Figure 3), meeting water quality objectives at nearly all locations.

Table 5: Summary of Estimated TN Loads to Newport Bay that show that TMDL loading limits are predicted to be met by implementation of the NTS Plan.

Load to Newport Bay	Dry Season Low Flow	Wet Season Low Flow
Without Plan (lbs/season)	**200,000**	**237,500**
Load Removed by NTS (lbs/season)	**119,500**	**108,000**
With Plan (lbs/season)	**80,500**	**129,500**
TMDL (lbs/season)	**153,861 (2007)**	**144,364 (2012)**



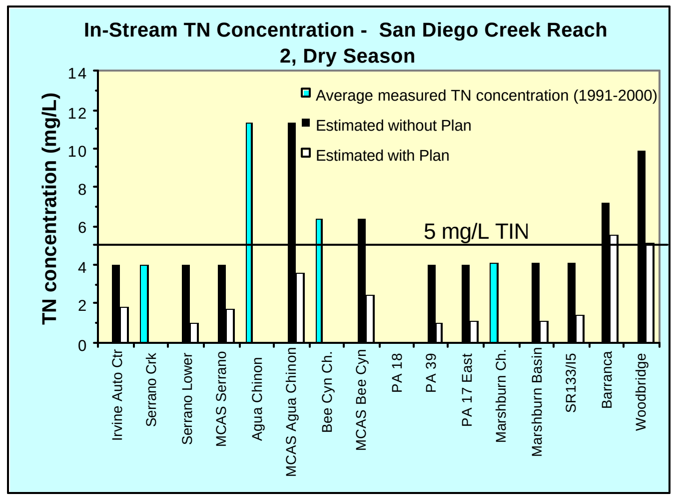


Figure 3. Measured and estimated In-stream TN Concentrations at various locations throughout the watershed.

Estimated Sediment and Phosphorus Removal.

Monitoring data indicate that sediment loads are strongly linked to winter storm flows and that highest sediment loads occur in above average rainfall years. Sediment reduction was therefore modeled only for storm flow conditions. However, not all sediment sources were modeled as indicated in Table 6. By far, the majority of the sediment loads are associated with channel erosion and scouring from in-stream sediment basins, although the TMDLs do not recognize this major source directly. In-stream sediment sources were not modeled because they are being managed through the implementation of the Sediment Control Section 208 Plan. Only urban and open space land surface sources of sediment were included in the model. The land surface sediment loads include sources from urban and agricultural land uses, runoff from open space, and construction activities. Construction related sources, however, were assumed negligible at build-out.

Although the phosphorus TMDL is specified in terms of an annual load to Newport Bay, monitoring data indicate the majority of the phosphorus load is in runoff from storm events. Phosphorus is mainly present in particulate form, attached to sediments transported during winter storm flows. Therefore, phosphorus treatment was modeled only for storm flow conditions consistent with the monitoring information. Average annual phosphorus loads and removals were quantified with the storm flow water quality model, identical to the approach used for sediments. Only urban and open space land-use sources of phosphorus were modeled.

The NTS Plan was not intended to treat in-stream sources of phosphorus; therefore it was assumed that bank stabilization measures and other BMPs would effectively control in-stream sources at build-out.

Table 6: Summary of Sediment Sources, TMDL Allocations, and Modeling Approach

Sediment Source	TMDL Allocation (tons/year)	Modeled in NTS Evaluation
In-stream erosion & scouring from In-Line sediment basins	None	No
Dedicated open space	28,000 discharged to Newport Bay 28,000 retained in sediment basins	Yes
Agricultural	19,000 discharged to Newport Bay 19,000 retained in sediment basins	Yes
Urban (commercial, residential, transportation, and industrial)	2,500 discharged to Newport Bay 2,500 retained in sediment basins	Yes
Construction activities	13,000 discharged to Newport Bay 13,000 retained in sediment basins	No

The storm flow model is based on rainfall/runoff relationships for the annual precipitation record from 1978-1998, as well as the average annual rainfall for this 21-year period. Model results estimate that NTS facilities remove about 1,600 tons/yr (1,451,000 kg/yr) of sediment during average rainfall conditions, or about 25 percent of the mean annual sediment load attributed to urban and open space land sources under build-out conditions. The NTS facilities would remove an estimated 7,300 lbs (3,311 kg) of TP per average year (Figure 4), or about 11% of the annual TP load from urban and open space sources. The 2012 TMDL target for TP (62,000 lbs/yr or 28,120 kg/yr) would be met in all but the wettest rainfall years. The two years where the TMDL was not met were the two highest rainfall years in the 21-year record, with 1998 also being a record rainfall El Nino year.

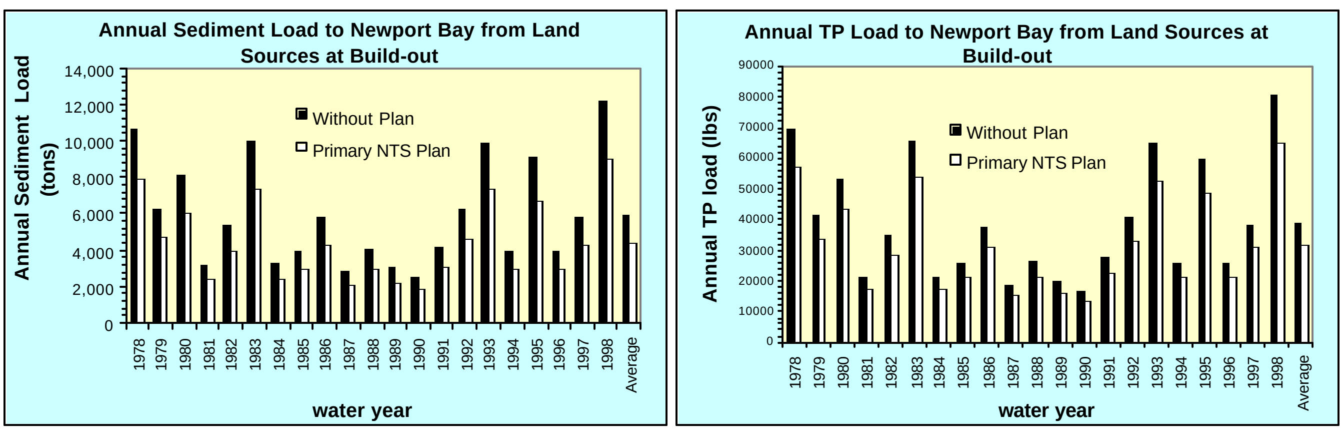


Figure 4: Estimated Sediment and TP Loads to Newport Bay from Storm Runoff.

Estimated Coliform Removal

The TMDL for pathogen indicators (fecal coliform bacteria) is valid throughout the year under all flow regimes. Therefore, fecal coliform removal was modeled for both low flow and storm flow conditions. Low flow conditions were modeled as a time series for comparison with monitoring data from a one-year monitoring period beginning in April 1999. Modeling results (Figure 5) indicate that during dry weather base flow conditions, fecal coliform concentrations would be reduced below the 30-day geometric mean standard of 200 MPN/100mL. The maximum 400 MPN/100mL standard would be met in most, but not all, of the dry season low flows. The standards are not met during the wet season base flow conditions.

The removal of pathogen indicators from storm runoff was modeled as equivalent fecal coliform loads. Modeling results suggest the NTS facilities will reduce fecal coliform concentrations by about 20 percent, but that concentrations entering Newport Bay will remain well above the TMDL targets during storm flow conditions. The inability to meet TMDL targets in the wet season runoff is attributed to the overwhelming pathogen loads generated during storm events.

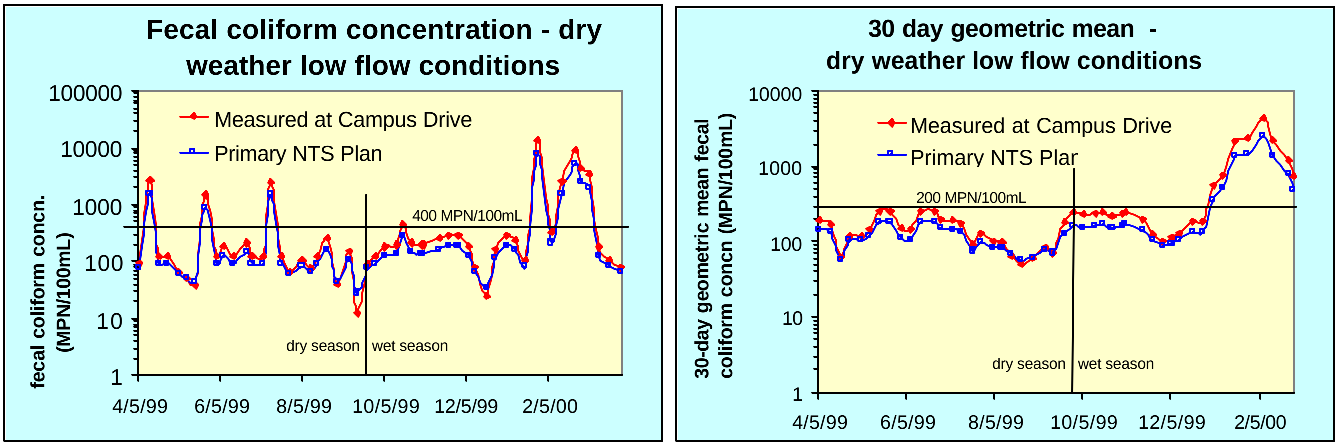


Figure 5: Measured and Estimated Fecal Coliform Concentrations

Estimated Metals Removal

Monitoring data indicate that the majority of metal loads in San Diego Creek are sorbed metals associated with sediment loads from winter storm events. Therefore, assessment of metal load reduction was carried out for total metal loads under storm flow conditions. Removal of total metals in NTS facilities was evaluated for copper, lead, and zinc. Translators were used (Table 7) to estimate the dissolved metals fraction of the estimated total metal loads for comparison with the draft TMDL.

Table 7: Fraction of Dissolved Metals in Total Metal Concentration Measurements

Metal	Estimated Fraction Dissolved – storm flow (1)	Estimated Fraction Dissolved – low flow (2)
Copper	41.4 %	82.8 %
Lead	17.5 %	37.9 %
Zinc	37.3 %	61.8 %

(1) Based on average concentrations in storm monitoring data.

(2) Based on average concentrations in base flow (dry weather) monitoring data.

Average annual loads to Newport Bay from urban and open land sources for total copper, lead, and zinc are estimated at about 2,700, 1,100, and 21,000 pounds, respectively. The NTS Plan is estimated to remove about nine percent of the total copper and lead loads, and about 13 percent of the total zinc load attributable to urban and open land sources. The estimated annual total metal loads were converted to average annual dissolved metal concentrations to allow comparison with the TMDL objectives. Results indicate (Table 8) that the TMDL objective at the large and medium flow regimes is achieved on ‘average’ at build-out for both with and without NTS Plan conditions. The results suggest that TMDL compliance is most easily achieved for lead and zinc and is more difficult to achieve for copper. These ‘average’ results to do not indicate the frequency at which occasional exceedances could occur.

Table 8: Estimated Average Annual Dissolved Metal Concentration in Storm Flows

Metal	Average annual total metal load in lbs at build-out (1)			Average annual dissolved metal concn in storm flow at build-out (ug/L) (2)			TMDL for medium flow regime (182-814 cfs)		TMDL for large flow regime (>814 cfs)
	Without Plan	With Plan	Initial Phase	Without Plan	With Plan	Initial Phase	Acute (ug/L)	Chronic (ug/L)	Acute (ug/L)
Copper	2970	2680	2790	12.1	10.9	11.4	30.2	18.7	25.5
Lead	1240	1130	1170	2.1	1.9	2.0	162	6.3	208
Zinc	23800	20400	21600	87.4	74.9	79.3	243	244	135

Selenium Removal

The design of the selenium treatment wetland at Site 67 was partially based on a successful treatment facility operating near the San Francisco Bay, which has similar site characteristics (Hansen et al., 1998). This facility was able to achieve selenium reduction below the water quality standard of 5 ppb. The proposed selenium treatment wetland at Site 67 is located in the historical marsh region, which is thought to be a significant source area in the watershed. This facility is estimated to remove between 235-500 lbs (107-227 kg) per year, or about 20 to 50 percent of the low flow selenium loads to Newport Bay. While the facility will significantly contribute to the reduction of low flow selenium loads, it may not, by itself, allow for attainment of the proposed TMDL targets. This is because other tributaries also contribute selenium loads to Newport Bay.

As selenium removal is relatively less well-understood, and in particular, is much less well-understood as an anoxic treatment system, the project has conducted column tests of different materials including chopped cattails, coconut shells, and green waste, as potential carbon-providing media for the anoxic treatment design. The next testing that is currently underway is at the mesocosm scale. The media that was chosen for further testing was the chopped cattails. Two side-by-side mesocosm facilities have been built to provide longer-term testing. The latest results of this testing will be presented at the conference and will also be available on the project web site when complete. Initial results are showing that selenium is being reduced to below laboratory detection limits.

Toxics Removal

The effectiveness of the NTS Plan for removing pesticides and organic compounds was not quantified because there is insufficient information about the sources of these compounds and about their treatment effectiveness in constructed wetlands. A literature review suggests the pesticides diazinon and chlorpyrifos have characteristics amenable for effective treatment in constructed wetlands; namely they are relatively insoluble, they are moderately to strongly sorbing, and they exhibit low to moderate persistence in soils. Limited data from the existing water quality treatment wetlands at the San Joaquin Marsh indicate that a high level of diazinon removal is occurring in the marsh.

Elements of NTS Plan

Maintenance

Regular and unscheduled maintenance activities will be required for all NTS facilities. Safe Harbor and access agreements will be processed to ensure that maintenance requirements can be carried out. Maintenance activities will include: trash and debris removal, pump servicing, vegetation removal and planting, sediment removal, installation and removal of seasonal weirs, vector control activities, and emergency repairs. Minimization measures will be undertaken to limit impacts to wildlife and habitat from maintenance activities.

Monitoring

Monitoring is a key component of the NTS Plan. There are three aspects to the monitoring program: routine monitoring, site performance monitoring, and TMDL compliance monitoring. Routine monitoring activities include site inspections, sediment accumulation monitoring, vegetation monitoring, monitoring of pollutant accumulation and distribution, and vector pest monitoring. Detailed performance monitoring will be conducted for a few selected NTS facilities to evaluate their treatment effectiveness and operating constraints. Experience gained from these assessments will be used to improve designs and operation practices of the NTS facilities. Regional monitoring will be conducted to assess the performance of the entire NTS network, in combination with other BMPs, for meeting the TMDL and other goals.

Vector Control

Wetlands can provide breeding habitat for numerous pests and vectors, most notably Mosquitoes. A comprehensive Vector Control Plan was developed, which includes the use of Mosquito Fish and the application of a natural microbial pesticide (*Bacillus thuringiensis israeliensus,* Bti) for the control of mosquitoes. With the increasing attention being paid to West Nile Virus, the control of Mosquito's will be increasingly important. The Vector Control Plan was developed with the local vector control agency. Implementation of the plan will be carried out by the same agency to ensure its success. With the West Nile virus concerns, the Vector Control Plan is receiving additional attention, as it should.

Program Modification

The NTS Plan is intended to be flexible. The NTS Plan would be formally evaluated on a regular basis to ensure that it is working as intended and to evaluate changes to the program that can improve the overall performance. Sites could be added or deleted in response to new opportunities, needs, or constraints. Site designs and operation practices could be changed as monitoring experience is gained.

Example Designs

The first example of an urban retrofit for establishment of constructed wetlands is the El-Modena/Irvine Retarding Basin. This 9.5-acre (2.84 hectare) retarding basin is located within a fully developed residential and highly urban setting. The basin was designed to retard peak flood flows in the adjacent El-Modena/Irvine Channel, which drains approximately 1.6 mi^2 (4.14 km^2) of residential areas in the upper reaches of the Peters Canyon Watershed.

The basin was originally designed with a water park in the floor of the basin, below the flood allocation pool, which is considered dead storage. The water park was to include a live stream and a waterfall, but was never implemented. The dead storage area is seen as the bare earth region in the photos shown in Figure 6. Notice the mounded area in Photo 2, which was to have been an island in the center of the water park. The basin is dry throughout most of the year, as winter storms of the magnitude that would cause any flow into the basin occur very infrequently. A portion of the flood flows that are infrequently diverted into the basin are retained in the dead storage area below the flood allocation pool. This water either infiltrates or evaporates.

Figure 6: El Modena/Irvine Retarding Basin. View in Photo 1 is from the upper end, near the diversion location. View in Photo 2 is from the lower end, near the discharge location.

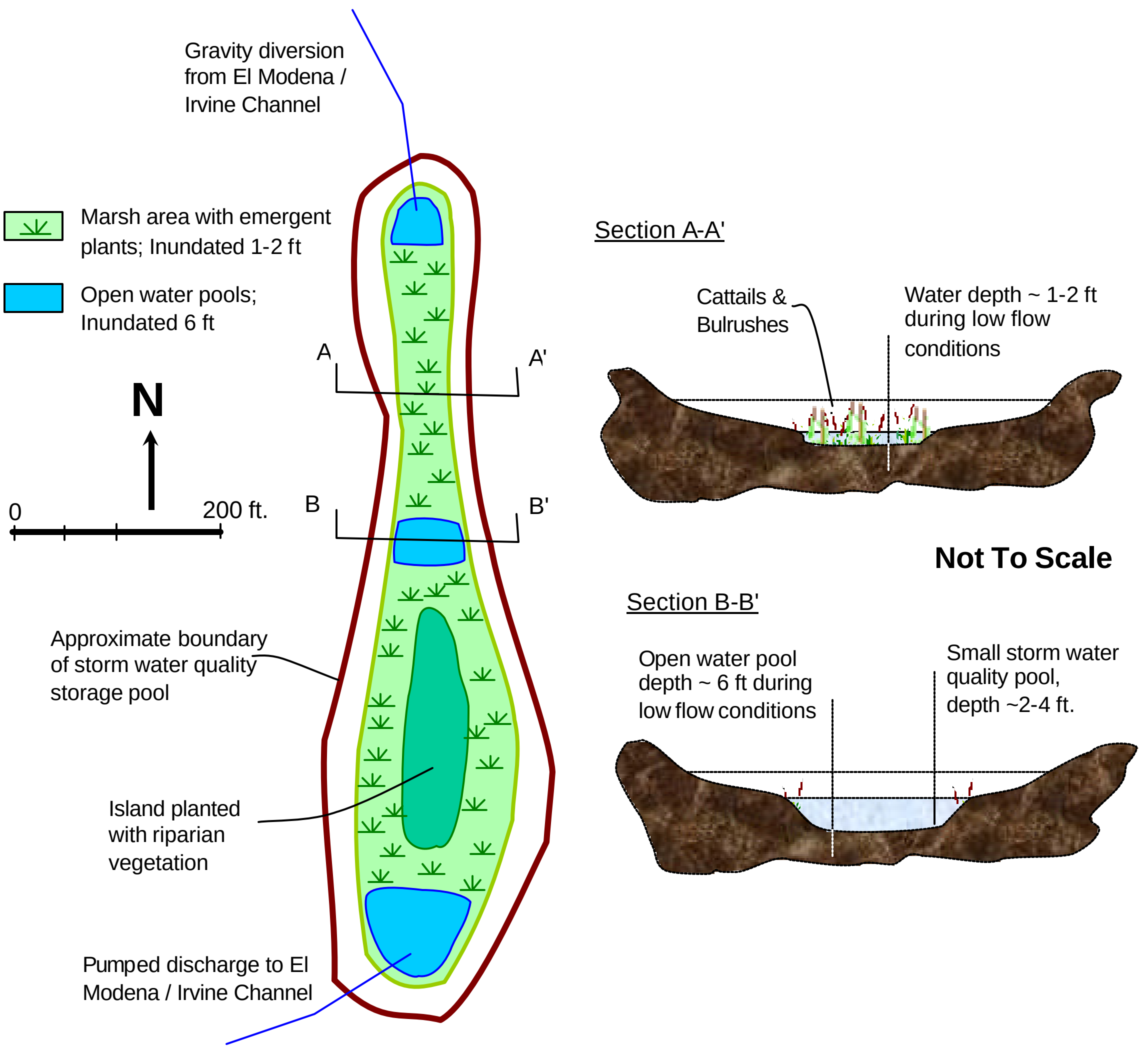


Figure 7: Conceptual Design of a Constructed Wetlands Retrofit in the El Modena/Irvine Retarding Basin.

The retrofit concept is to establish constructed wetlands within the dead storage area in the bottom of the El-Modena/Irvine Retarding Basin. The wetlands would treat nuisance (low) flows, and runoff from smaller storms, as well as the first-flush flows from larger storms. A geotextile clay liner would eliminate infiltration losses from the wetland. Figure 7 shows a conceptual design of the proposed facility. The wetlands consist of 0.66 acres (0.27 hectares) of shallow water marsh with emergent cattails and bulrushes, 0.17 acres (0.07 hectares) of open water areas 4-6 ft (1.2-1.8 m) deep, and 0.5 acres (0.2 hectares) of re-vegetation area for native riparian habitat. The estimated average low flows during the dry and wet seasons are 0.07 cfs (2 L/s) and 0.12 cfs (340 L/s), respectively. The average residence time during low flow conditions is about 10 days. The stormwater quality treatment pool is on top of the low flow water level. The stormwater treatment capacity is about 2.7 acre-ft (3,330 m^3) (average depth of 2 ft or 0.6 m), with a detention time between 48 and 96 hours (draw-down time).

A second example site includes an "in-line" facility. This is one that will only treat low flows. These facilities will be located with the drainage system and will provide treatment of low flow discharges. During storm events they would not be expected to provide any treatment. One of these sites is the Woodbridge In-line facility. Figure 8 shows several photographs of the existing channel. The channel in much of the reach is an earthen channel with limited habitat value. However, the placement of wetlands within such a system is expected to improve habitat while also improving water quality. In California, the use of "in-stream" treatment facilities has been controversial, with at least one Regional Water Quality Control Board not allowing the use of "regional" treatment systems such as these. It is the author's opinion that not allowing regional treatment or not allowing treatment within a highly degraded stream such as this one is not a wise ecological approach.


Photo 1 & 2 - San Diego Crk, looking downstream at grade control structure between East Yale Loop and Creek Rd.

Photo 3 – San Diego Crk, looking upstream from grade control structure toward E. Yale Loop overpass.

Photo 4 – San Diego Crk looking downstream from grade control structure at energy dissipaters.

Figure 8. Woodbridge Site Photographs

Figure 9 shows an aerial photograph and conceptual layout of the facilities. Figure 10 shows a concept sketch of one of the facilities. The weirs may also require more maintenance than off-line facilities, including removing materials over the course of the year to maintain pooled water above the weirs. In a very space-constrained watershed, however, where dry-weather water quality is an issue, these types of facilities can provide significant benefits.

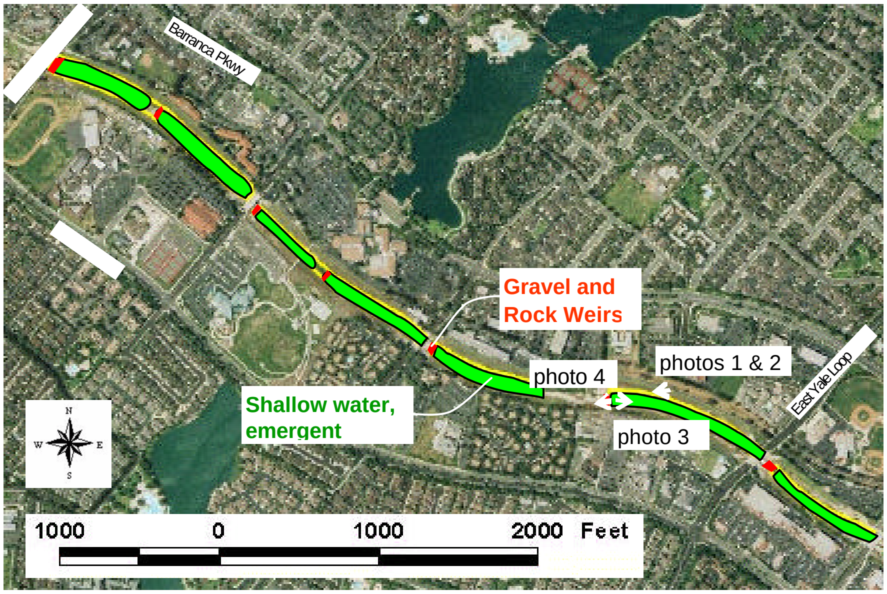


Figure 9. Aerial Photograph and Conceptual Layout of Woodbridge Facility showing the planned series of shallow linear wetlands within San Diego Creek.

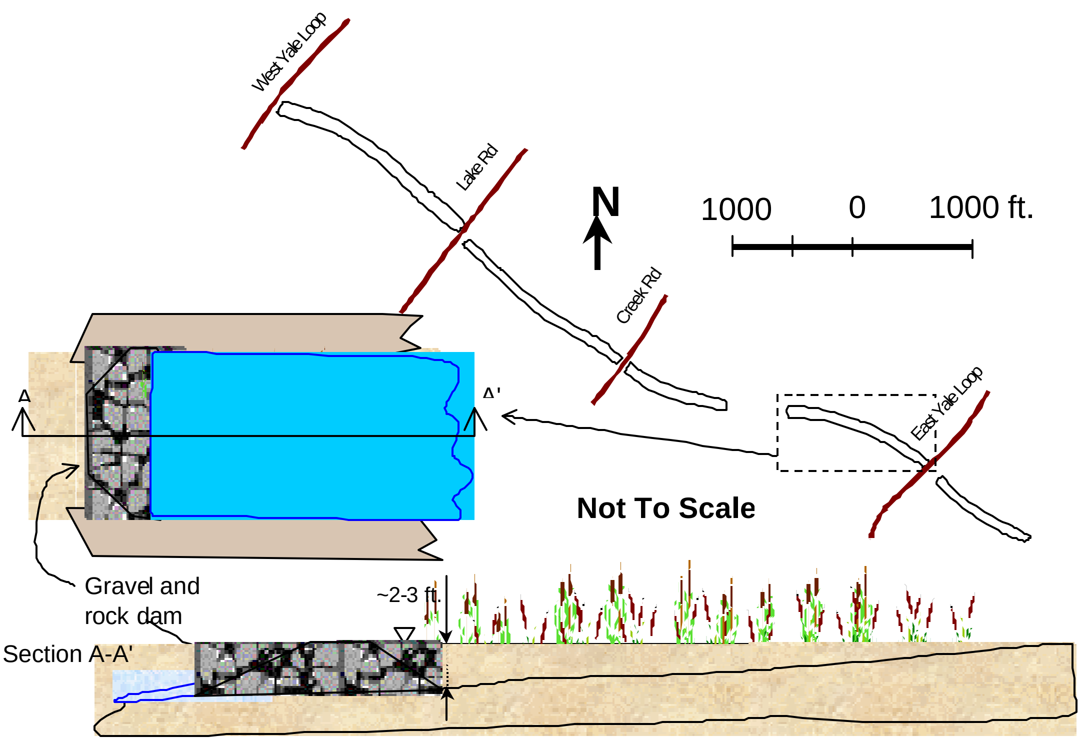


Figure 10. Conceptual Drawing of In-line Facility, showing a plan view along with cross-sections of the planned gravel and rock dams (2 to 3 feet in height).

Some professionals argue against “in-line” or “in-stream” treatment. However, man-made earthen or rip-wrapped channels with engineered drop structures are not natural streams. Because of the degraded status of these highly maintained flood control channels, the NTS Plan would improve both habitat and water quality. In a highly urbanized watershed such as the San Diego Creek Watershed, in-line treatment such as this may be one of the few options for improvement in water quality over the shorter-term.

Discussion

The estimated cost to provide low-flow treatment of urban runoff in a sanitary treatment plant is greater than $60 million in construction costs, with annual operation and maintenance costs of about $5 million. The NTS System is expected to cost about $12.2 million for first-phase construction of the 13 NTS sites, and $1.1 million annually for ongoing operations, maintenance, and monitoring. This does not include the cost of projects funded by local developers or costs of second-phase regional project sites. A comparison of the capital cost per unit pollutant removed, indicates that the treatment plant is about three times more costly for TN removal from low flows, and about twice as costly for removal of copper from storm runoff.

The San Diego Creek Natural Treatment Systems Plan has been designed to result in a cost-effective solution that meets many goals. The effectiveness of the NTS Plan will ultimately be determined through the long-term coordinated efforts, spanning the planning, implementation, and program evaluation stages. Observations and conclusions from the development and initial evaluation of the NTS Plan are:

- Retrofit options are necessary to meet water quality goals in watersheds that are highly developed. It is possible to develop cost-effective regional retrofit solutions on a large watershed basis that would result in significant water quality improvements;
- Existing flood control basins and conveyance facilities can be cost-effectively retrofitted;
- The NTS Plan has resulted from a cooperative problem-solving focus by municipalities, development interests, water and sewer providers, and environmental groups. This effort has not focused on just meeting single-purpose requirements, and therefore has resulted in a more robust plan. Consequently, the NTS approach can achieve multiple benefits, including habitat and aesthetic values;
- The NTS Plan was developed in a relatively short 15-month time frame, demonstrating that planning efforts can be accelerated when there are motivated interests; and
- Cost-recovery from other sources of funds is possible when urban runoff treatment requirements include treating dry weather flows.

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